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Survey of Model-Based Design Reviews: Practices & Challenges?

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Abstract

The design of large-scale engineered systems relies on the extensive use of models. Although there are few papers that study design review practices, we did not find any on model-based design reviews. Thus, we undertook a survey to collect current practices and challenges. We found that reviews are mainly synchronous co-located or remote meetings that involve various profiles who need to access and share models, but that they pragmatically give them up and prefer to comment on PowerPoint-like slides containing screenshots of models except when the meeting gathers only experts in model-based design.

Keywords: model-based systems engineering (MBSE), design review, design practice, design models

1. Introduction

1.1. Context

The design of complex engineered systems is more and more relying on the extensive use of models to replace the traditional document-based approach. Although the intent remains the same, depending on the community, Model-Based Systems Engineering (MBSE), that is, "*the formalized application of modelling to support system requirements, design, analysis, verification and validation activities*" (Walden *et al.*, 2015) may be known as Model-Centric Engineering (MCE), Model-Based Engineering (MBE), Integrated Model-Centric Engineering (IMCE), Interactive Model-Centric Systems Engineering (IMCSE), Model-Driven Development (MDD), or Model-Driven Engineering (MDE) (Bone *et al.*, 2019). In this paper, we will use the concept of Model-Based Design (MBD) since it concentrates on the design activity without limiting the scope to the systems engineering approach. A MBD review is a design review in a design process where models replace the traditional document-centric approach. When a design relies on the widespread adoption of models, we observe that all stakeholders involved in the design process must cope with new challenges such as the learning of new languages and modelling environments (Herzog *et al.*, 2005, 2014), the interdependencies among models (Baduel *et al.*, 2018), the consistency among multiple modelling views (Herzog *et al.*, 2005), etc.

1.2. Research aim

A literature review on the paradigm shift from document-based to model-based design shows that there are very few papers providing industrial feedback and academic analyses to better understand how the extensive use of models impact design reviews (Huet *et al.*, 2007; Verlinden *et al.*, 2009). Nevertheless, the literature shows that reviewing a design in a MBSE approach is not trivial for several reasons - e.g. to continuously learn new modelling notations in a volatile software environment (Bayer, 2018), or to share the models in a meeting gathering experts and non-experts (Chen *et al.*, 2019) - and that the added-

value of models is often drastically reduced to screenshots in PowerPoint-like slides (Bayer, 2018). To better understand the practices and challenges of MBD reviews, especially the way design review participants communicate through models and the related difficulties, we conducted a survey and present the results in this paper.

2. Literature Review

A design review is a meeting to collaboratively evaluate the progress and improve the design through the communication and synchronization of design information (Huet et al., 2007; Wolfartsberger, 2019). Although the review is a crucial activity in product design, little research has been done to better understand it. This is no surprise because "*sharing understanding from practice can be difficult since publishing purely descriptive papers can be a challenge as reviewers demand methods or multiple case studies*" (Gericke *et al.*, 2020). In this section, we compile knowledge on design reviews from academic researches and industrial practices found in the literature since 2010.

Regarding the goals pursued by a design review, there is no agreed-upon taxonomy. The goal seems to depend on the phase of the product development process (Chen *et al.*, 2019), brainstorming of concept ideas during conceptual design for instance, or to perform gate review. To achieve these goals, participants needs many functions including, but not limited to, the capture of interactions and reflections, freehand sketching, interactive display, the presentation of design alternatives, the archival and retrieval of reviews with shared access (Verlinden *et al.*, 2009). A wide range of media is used during these meetings. Most papers deal with the review of 3D models (Chen *et al.*, 2019). At the JPL, the model-centric engineering approach, which is closer to our scope, includes numerous models: mass/power/data equipment lists, block diagrams, modes, scenarios, requirements, functions, etc. (Bayer, 2018). The preferred method for sharing design information depends on the way a review is conducted. Design reviews can be co-located or remote and synchronous or asynchronous. Previous studies (Chen et al., 2019) showed that co-located live meetings are more common even for multi-national companies and that the increase of the project maturity leads to more and more mixed, online remote or asynchronous meetings. Whether co-located or remote, the models shared during a review require the access to specific modelling environments. As software supporting the review, reviewers most commonly use a native Computer-Aided Design (CAD) environment rather than a viewer, or a fixed view, or a physical prototype (Chen *et al.*, 2019). Although CAD environments are relatively popular in companies, the study shows that CAD designers rely on 3D CAD during design reviews more so than non-CAD designers. In addition, many more non-CAD designers reported using physical prototypes as their main tool compared to CAD designers. We also know that the use of the native modelling environments is limited to meetings gathering domain experts and that PowerPoint-like slides are preferred when a stakeholder wants to compile data from models in a story to be told to non-experts (Bayer, 2018). To integrate experts and non-experts in reviews, virtual reality gains more and more interest, especially for reviewing software (Averbukh *et al.*, 2019; Oberhauser and Lecon, 2017; Schreiber *et al.*, 2019), hardware (Aromaa, 2017; Wolfartsberger, 2019) and, more recently, engineered systems (Romero *et al.*, 2021) as it enables a human-centred design approach where an iterative multidisciplinary process serves to drive and refine the design by successive participatory user-centred evaluations (Aromaa *et al.*, 2012).

2.1. Model-based design review challenges

In 2018, a study (Bayer, 2018) evaluated the progress of the integrated model-centric engineering initiative at the NASA's Jet Propulsion Laboratory (JPL) on the first project with the widespread adoption of MBSE - the Europa Clipper Mission - between 2010 and 2017. At that time, the major issue was that "design description comes together only infrequently when preparing for major reviews" and the JPL expected design reviews that consist largely of model inspection and validation. At the end of the project, the JPL states that the design description is integrated and analysed monthly. In addition, informal working-level reviews often use the model (Mass/Power equipment list, block diagrams, modes, scenarios, requirements concepts, functional description) directly. However, the authors report that the three major gate reviews (Mission Concept Review, System Requirements Review/System Definition Review, Preliminary Design Review) relied upon hand-crafted PowerPoint-like slide decks,

but compared to traditional reviews, much more content came directly from the system models (Bayer, 2018). Preparing a PowerPoint-like presentation is seen as the opportunity to extract and organise information to tell a story without any major difficulties that may occur while exploring models. To expect design reviews that consist of model inspection and validation, the study points out that reviewers must become comfortable with modelling notations. To sum up, MBD reviews:

- include more and more models in addition to the 3D geometry.
- requires a learning period so reviewers become comfortable with modelling notations.
- force reviewers to continuously cope with the mushrooming of modelling notations.
- rely upon native models when the meeting gathers experts.
- rely upon PowerPoint-like slides when the meeting includes non-experts.
- require to extract and organise the content to tell a story, especially for non-experts.

3. Method

In this section, we detail the three-step method that we followed to define, distribute, and analyse the survey on model-based design reviews. The survey method was preferred because the aim of the study was to quantitatively describe the current MBD practices and challenges according to experts and non-expert's viewpoints.

3.1. Survey definition

We created a survey to collect and analyse industrial practices regarding the use of models during design review sessions. The term "Model-Based Design" was preferred to alternatives such as "Model-Based Systems Engineering" and "Model-Centric Systems Engineering" (Bone *et al.*, 2019) since it is the most inclusive. The design concerns any product but model-based design being a design approach for complex systems, we expect to collect responses from professionals involved in the design of large engineered systems. The level of involvement of respondents is not limited to model-based design experts as we expect to acquire practices and challenges from any stakeholder who is continuously or sporadically engaged in a model-based design. To reach a maximum of model-based design practitioners, we created a web-based survey with the Framaforms solution. To maximize the number of answers, we asked 9 questions in English that takes no more than 20 minutes. The questions were defined based on our subsequent MBD experience in industry and academia as well as missing knowledge in the literature. Moreover, as the survey is part of a broad PhD, the questions concentrate on the identification of current practices and problems that would help us to refine the scope of the thesis and to elucidate required visualisation and interactions capabilities to better support MBD reviews.

3.2. Survey distribution

The survey was mainly distributed to associations within which the principal author is involved in. Their selection was driven by the need to get a representative sample of people opinions: public and private sector, systems engineering and other disciplines, national and international, etc. We started the distribution via the mail list of the Model-Based Systems Engineering working group of AFIS French Chapter of INCOSE which includes 115 people with a majority of engineers and managers in industry and a few academic researchers. Another systems engineering community that we addressed was the program ATLAS initiated by the French national organisations for standardisation in coordination with representatives of the French industrial sectors. Among the relevant French associations, we also shared the survey to S.mart which is the national academic community for Industry 4.0. It includes a majority of academic researchers which makes a good balance with the previous community of AFIS. Indeed, collecting answers from industry may seem to be the best strategy, but it is also crucial to get the vision of academic researchers who are daily involved in industrial partnership providing us with an external view on design practices compared to state-of-the-art researches. We did not limit our survey to French communities, but also shared it with the Design Society which includes a majority of academic researchers in the broader scope of product design. The working group Analysis & Design of the Object Management Group (OMG) was also directly solicited to answer our questions. This group is mainly concerned with systems engineering practices including the standardised specification of methods and

tools for developing and managing large-scale systems. To enlarge the targeted audience, we used social networks to distribute our survey, especially the first author's LinkedIn page, the INCOSE LinkedIn page, and the MBSE LinkedIn group.

3.3. Survey analysis

The survey responses were exported from the Framaforms platform as an Excel file. The raw data set is in open access[1]. We analysed this raw dataset using the software RStudio that is based on the free software environment for statistical computing and graphics. The R source code is in open access too[2] in the Gitlab project[3].

4. Results

This section answers the set of questions based on the statistical analysis of the raw datasets.

4.1. Who are the respondents?

Among the 61 respondents, the majority of them come from the aerospace/defence industry and education/research. This is no surprise since our communication channels to contact MBSE practitioners targeted systems engineering communities where actors from Aerospace/Defence are more involved than other industry sectors. The high number of academic researchers results from our close relationships with colleagues in social networks (e.g. LinkedIn) and our involvement in academic associations such as the Design Society. Some respondents, especially consultants and academic researchers, work in several industry sectors. The rest of the respondents is a blend of professionals from industry sectors where systems engineering is a common approach. 88 % of responses (n=54) come from Europe, especially France with 60 % (n=37) of answers. Almost 10 % (n=6) come from North America and 2% (n=1) come from Asia. A system engineer, which is also known as a systems architect, is the most frequent core activity of the respondents. The function of product design is also well represented in our survey, which includes respondents occupying a transverse function such as manufacturing, and safety, or quality engineering.

4.2. What is your experience in using model-based design?

We assume that some key differences are separating MBD Experts' and Others' experiences in model-based design reviews. Thus, we intended to categorise respondents into two categories – designers (i.e. systems engineers and product designers) VS. others – to acquire the perspective of designers practising model-based design regularly and stakeholders who do not are always familiar with such models but whose involvement in design reviews is crucial. However, the categorization "designers VS. others" is difficult since it is a multiple-response set allowing respondents to select several functional areas they are involved in. For example, someone who is a systems engineer may logically answer that he is also involved in project management and safety engineering activities. This leads us to a cumbersome choice whether he is a designer or not.

Alternatively, based on the answers to the question "What is your experience in using model-based design?" (Figure 1), we have decided to create two categories (Figure 2). The first category corresponds to the 34 respondents (55%) who answered that they are daily involved in a model-based design. The second category gathers 28 participants (45%) including 17 who have been involved as an 'actor' of a model-based design, 5 who have been involved as a 'spectator' of a model-based design, and 5 who have never been involved in a model-based design. In other words, we distinguish model-based design experts and model-based casual practitioners or novices.

[1] https://gricad-gitlab.univ-grenoble-alpes.fr/pinquier/mbse_design_review_suvey/-/blob/master/Survey.xlsx
[2] https://gricad-gitlab.univ-grenoble-alpes.fr/pinquier/mbse_design_review_suvey/-/blob/master/Analysis.R
[3] https://gricad-gitlab.univ-grenoble-alpes.fr/pinquier/mbse_design_review_suvey

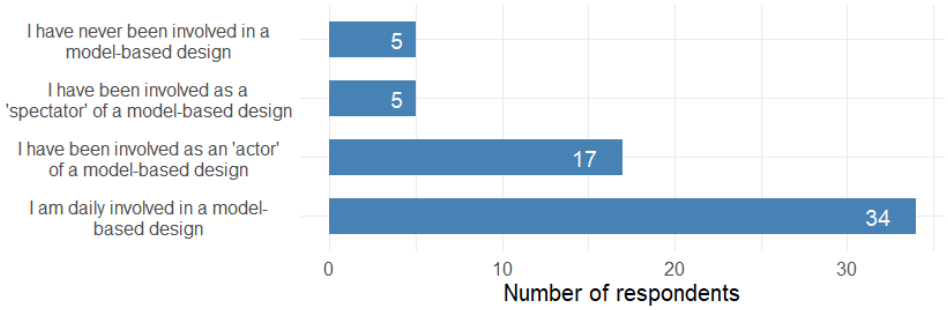

Figure 1. Answers to the question: What is your experience in using Model-Based Design?

4.3. Do you use models in your design activity?

MBD mainly relies on models for communicating information regarding the specification and architecture of a system (Figure 2). These models concern a majority of MBD experts. Detailed design models including systems simulation models and CAD models come next and we observe that these models are equally relevant for experts and non-experts. Finally, domain-specific models supporting safety and stress analyses are less frequent in MBD and seem to concern a small community of reviewers who are experts in a specific engineering discipline. Hence, we may assume that MBD is an engineering approach that concentrates on the early phases of a product development process and that there is a need to guarantee a digital continuity between conceptual and detailed design phases. Respondents claimed to use further models including ontologies, Life Cycle Analysis (LCA) and Material Flow Analysis (MFA) models, TRIZ, security-related models, cost, Business Processing Modeling Notation (BPMN), code and test-base generation, Component-Based Software Engineering (CBSE) and schedulability analysis models. Nevertheless, these suggestions are relatively rare since they have been mentioned by a unique respondent.

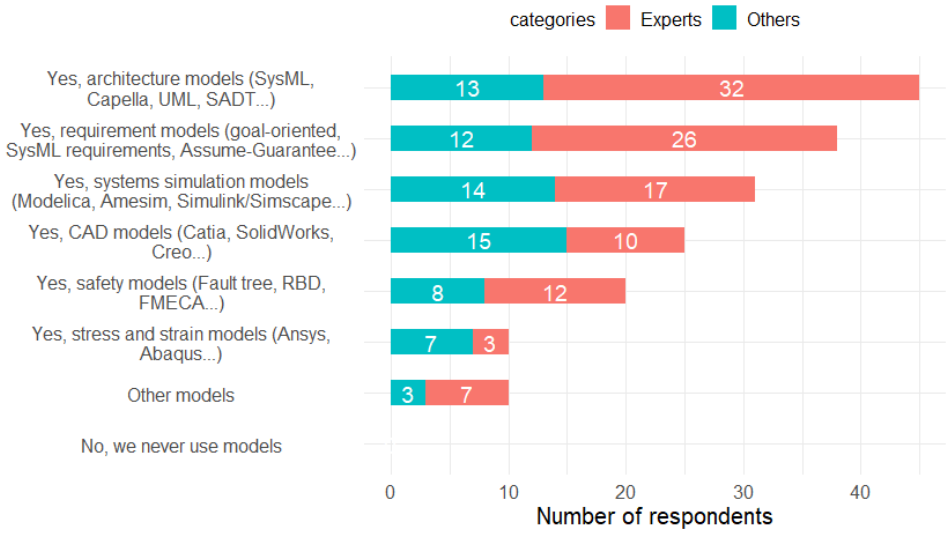

Figure 2. Answers to: Do you use models in your design activity?

4.4. Do you participate in (a)synchronous co-located or remote MBD reviews?

MBD reviews are synchronous and, conversely to a previous study (Chen *et al.*, 2019), we observe that remote meetings are more or less as frequent as co-located ones. This change is perhaps the consequence of the COVD crisis that forced people to collaborate in video conference meetings, which are progressively becoming a de facto standard way of conducting design reviews. Moreover, 24 respondents claimed to participate in asynchronous and remote MBD reviews. This translates the influence of software engineering (e.g. SysML is a UML profile tailored for systems engineering) onto

the development systems. For instance, the configuration management of models is relatively similar to the management of software code. Consequently, engineers make extensive use of tools such as Git that have been borrowed from the software development domain.

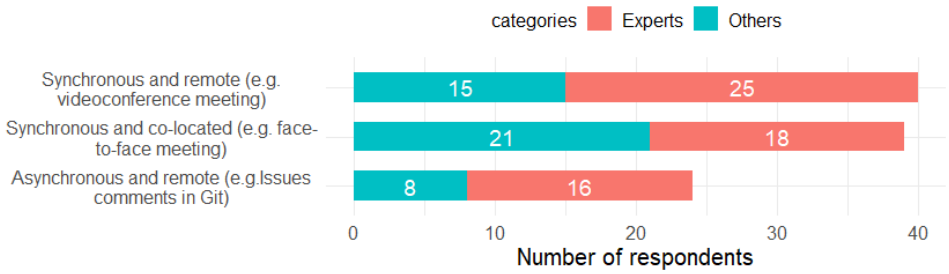

Figure 3. Answers to: Do you participate in (a)synchronous co-located or remote MBD reviews?

4.5. How long are the design reviews you attend?

According to our survey, a design review last between 1 and 2 hours and rarely exceed 2 hours, especially for non-experts in MBD.

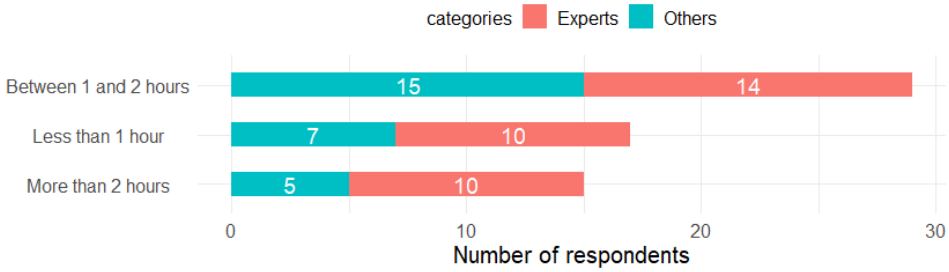

Figure 4. Answers to: How long are the design reviews you attend?

4.6. Do you (use) share models during MBD reviews?

Figure 6 shows that only 10 % of respondents (n=8) always conduct a MBD review. Although all design reviews are not model-based, 40 % (n=24) of both experts and non-experts are used to often share models. If we extend to the ones who share models from time to time, then we reach 72 % (n=44) of respondents. This means that the review environment shall facilitate access to models for any reviewer.

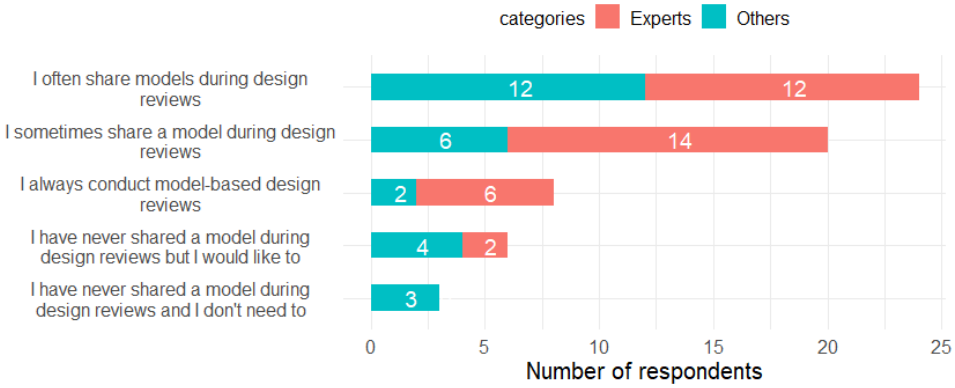

Figure 5. Answers to: Do you (use) share models during MBD reviews?

4.7. At which stage of the development process did the MBD review occur?

MBD reviews occur all along the product development process with an emphasis on systems architecture (Figure 6). However, respondents mentioned further activities such as idea generation, enterprise architecture, or customer feedback, but, in our definition, most of them (concept development, concept of operations, mission, concept development) belong to the systems architecture phase.

Figure 6. Answers to: At which stage of the development process did the MBD review occur?

4.8. Which goals do you address during MBD reviews?

Figure 7 shows that MBD reviews aim at supporting key milestones of the product development process, especially the validation of requirements and the verification of designs. In addition, MBD reviews play a crucial role to apprehend a system from different viewpoints and evaluating the impacts of a design change. 3 respondents mentioned complementary goals such as life cycle value proposition, the formalisation of needs towards subsystems or the development of CONOPS, but most of them (justification of the needs, stakeholder's satisfaction, preparing IVV Strategy) belong to the validation of requirements and verification of designs.

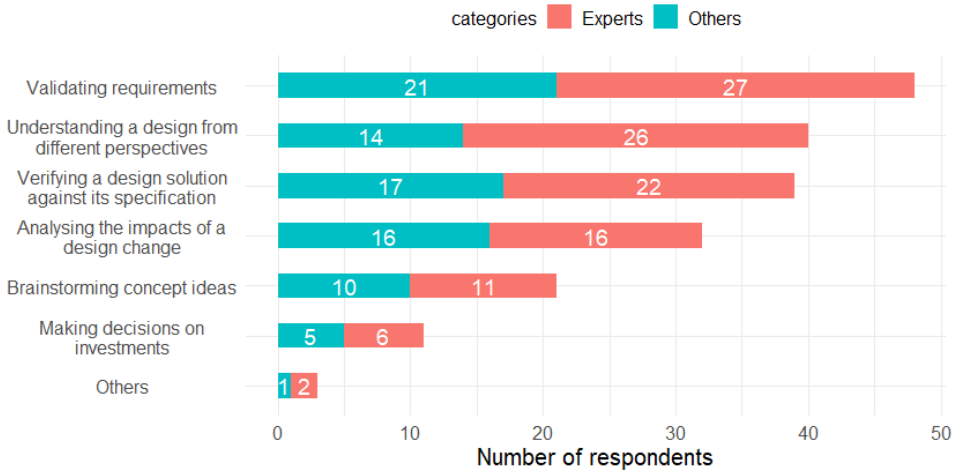

Figure 7. Answers to: Which goals do you address during MBD reviews?

4.9. How do you share models during design reviews?

Figure 8 shows that MBD reviewers are used to opening the models with the native editing software to share the content. However, statistics show that this approach is exclusive since it is more frequent with experts since they have the skills and licences to manipulate the editing software. If we concentrate on a solution that suits experts and non-experts, PowerPoint-like slides with embedded screenshots and videos of models and simulations of models remains the most popular one. Alternatives to the suggested solutions to share models during design reviews include printed drawings, automatic exports of models in documents or web-based UI, and, in very few cases, spatial-augmented reality and virtual reality environments to review 3D CAD models.

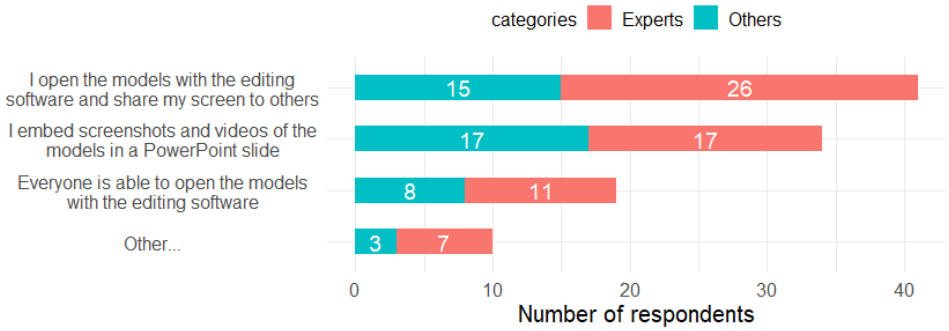

Figure 8. Answers to: How do you share models during MBD reviews?

4.10. How do you deal with models' interdependencies during MBD reviews?

In section 4.3, we observed that MBD reviews rely upon various models and we wondered how reviewers deal with interdependencies, especially implicit ones. For instance, when a reviewer wants to make sure that a given architecture block in a SysML diagram has a corresponding part/assembly in a CAD model and a system simulation model. Figure 9 shows that to deal with such interdependencies, reviewers open the models in software that shows everyone the interdependencies between the models. This tendency is unexpected since what we may expect at best is a product data/lifecycle management software that shows interdependencies between files in a database but not among the data (requirement, function, interface, geometry, failure mode, etc.) contained in files. More likely, we found that most respondents share PowerPoint-like slides with multiple screenshots and comment interdependencies orally rather than drawing the relationships between contents. A similar approach consists in sharing multiple windows at the same time, but this practice is less frequent since it requires to access native files and this is the reason why most respondents are experts. Very few people use multiple screens to share several interdependent models (e.g. 1 screen = 1 model). Consequently, we may assume that meeting rooms and remote videoconference solutions do not provide adequate hardware and/or software capabilities. As alternatives to suggested answers, respondents mentioned the Windchill Asset Library that shows links between Windchill Modeler models.

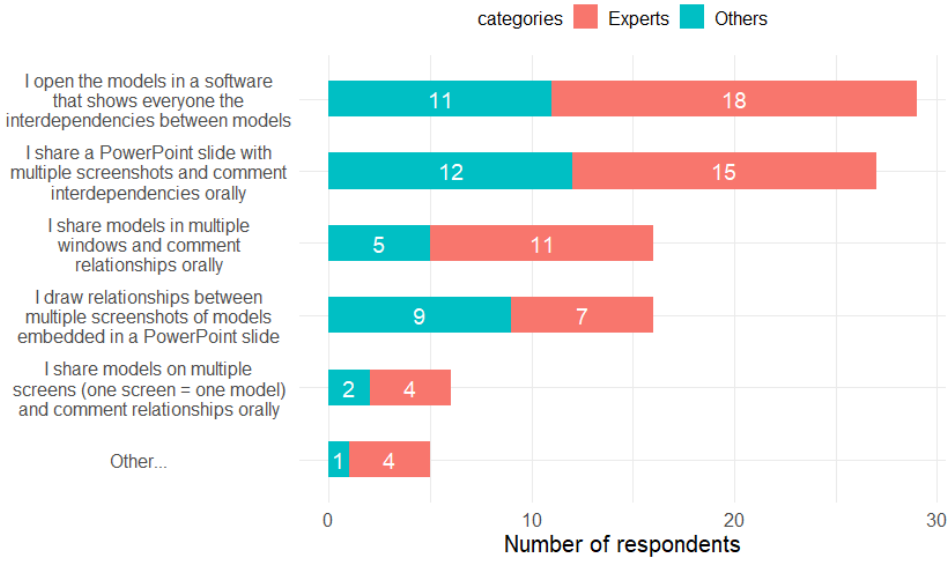

Figure 9. Answers to: How do deal with interdependencies among models during MBD reviews?

4.11. How do you capture decisions during design reviews?

The extensive use of models during design reviews does no significantly change the reporting practices since minutes remain the leading solution to capture design rationales and decisions (Figure 10). Nevertheless, an important part of respondents reports using textual annotations to capture decisions on

top of the models under review. Although researches in computational linguistics and natural language processing combined with big data have enabled engineers to develop remarkable automatic speech recognition software, design rationales remain captured in natural language statements. As alternatives to minutes, textual annotations of models, and voice recordings, we found chats in business social media as well as captures (e.g. comments, change history, etc.) in change management software (e.g. Jira).

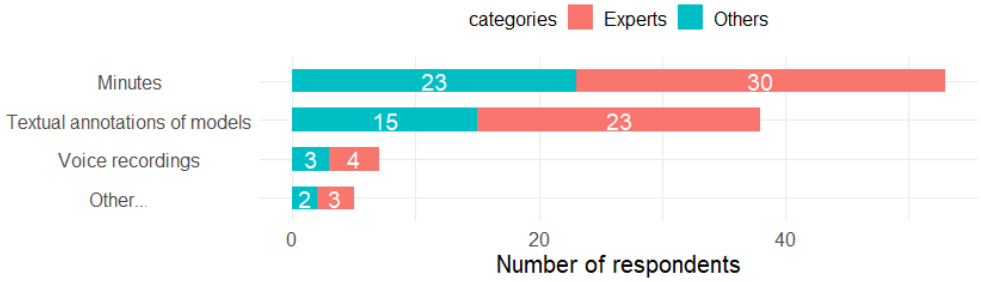

Figure 10. Answers to: How do you capture decisions during design reviews?

4.12. Do you face difficulties to understand models shared during MBD reviews?

Figure 11 shows that the major difficulty encountered by MBD reviewers include the consideration of implicit interdependencies among the models that materialise different viewpoints on the product. In addition, two important difficulties are the necessity to master numerous software for accessing and consolidating the content of models and the loss of information when sharing screenshots of models in a deck of slides. The use Domain Specific Languages and the mushrooming of software are less frequent difficulties. Respondents mentioned further difficulties including interoperability and semantic alignment (i.e. domain specific language), the level of understanding and viewpoints differs among the attendance, people from hardware teams are often reluctant to MBSE/SysML diagrams.

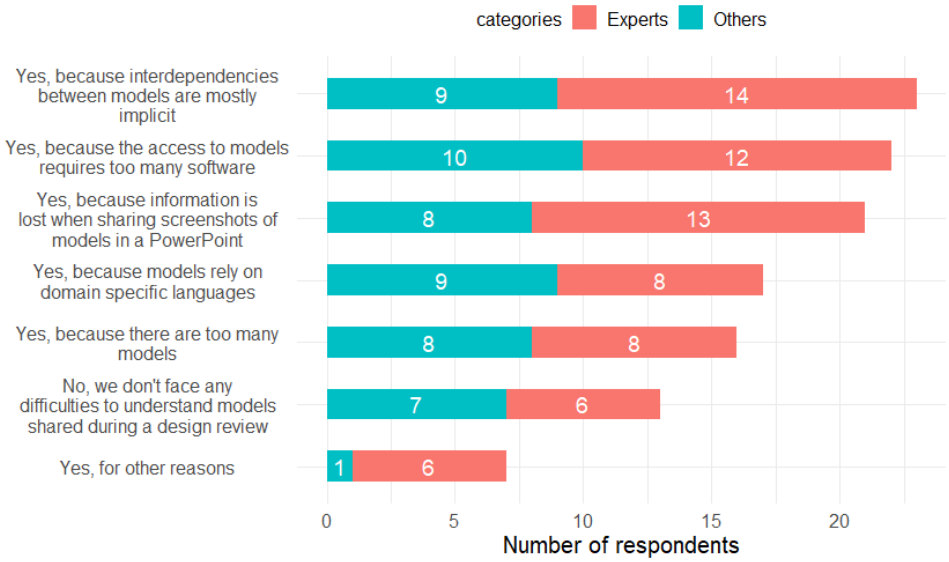

Figure 11. Answers to: Do you face difficulties with models shared during MBD reviews?

5. Conclusion

Model-Based Design (MBD) is progressively replacing the document-centric approach. This paradigm shift is leading to new challenges, such as the learning of new modelling notations and environments or the interoperability and sharing of models. Among the emerging difficulties, we wondered how the extensive use of models in product development process impacts design reviews. Thus, we undertook a survey to better understand the practices and challenges of MBD reviews. This survey extends the only work on the topic that was very briefly broached in NASA's feedback on MBSE value (Bayer, 2018). We found that MBD reviews are synchronous co-located or remote meetings that involve various

profiles who need to access and share models, but that they pragmatically give them up and prefer to comment on a slide deck containing screenshots of models except when the session gathers only MBD experts. One major limitation in this survey is the difficulty to distil sound observations for the broad community of MBD within which the definitions and practices are not always shared. As future work, we plan to invent new methods and tools based on advanced visualisation and interaction techniques such as virtual reality to offer a holistic multi-view of models to be reviewed in synchronous or asynchronous co-located or remote collaborative meetings.

Acknowledgement

We thank all respondents who took the time to distribute and complete the survey.

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